CLAIMS

1. Apparatus for heart pacing with hemodynamic improvement, comprising:

one or more electrodes, which convey electrical signals to respective cardiac muscle segments; and

signal generation circuitry, which applies an extended pacing signal, having an overall duration greater than three times a chronaxie time, to the one or more electrodes so as to pace the heart.

2. Apparatus according to claim 1, wherein the overall duration is at least 10 ms.

3. Apparatus according to claim 2, wherein the overall duration is at least 20 ms.

4. Apparatus according to claim 1, wherein the overall duration is less than approximately 100 ms.

5. Apparatus according to claim 1, wherein the cardiac muscle segments to which the one or more electrodes are applied are characterized by a refractory period, and wherein the overall duration of the signal is such that the signal terminates during the refractory period.

6. Apparatus according to claim 1, wherein the signal has a leading edge and a trailing edge, and wherein the trailing edge is characterized by an absolute rate of voltage change substantially smaller than that of the leading edge.

7. Apparatus according to claim 6, wherein the absolute rate of the voltage change is less than a minimum rate of change necessary to generate an action potential in the cardiac muscle segments.

8. Apparatus according to claim 1, wherein the signal has an amplitude at least three times as great as a threshold for pacing the heart, but not sufficient for cardioversion.

9. Apparatus according to claim 8, wherein the signal has a duration at least three times a threshold duration for pacing the heart at the amplitude of the signal.

10. Apparatus according to claim 1, wherein the extended pacing signal comprises a train of pulses.

11. Apparatus according to claim 10, wherein each of the pulses in the train has a pulse duration of at least 1 ms.

12. Apparatus according to claim 10, wherein the pulse train has a period of at least 5 ms.

13. Apparatus according to claim 12, wherein the pulse train has a period of at least 20 ms.

14. Apparatus according to claim 10 wherein the train of pulses comprises a plurality of biphasic pulses.

15. Apparatus according to claim 10, wherein the train of pulses has a duty cycle between about 10% and 50%.

16. Apparatus for heart pacing with hemodynamic improvement, comprising:

one or more electrodes, which convey electrical signals to respective cardiac muscle segments; and

signal generation circuitry, which applies an extended pacing signal, comprising a train of a plurality of biphasic pulses, to the one or more electrodes so as to pace the heart.

17. Apparatus according to claim 16, wherein each of the pulses in the train has a pulse duration of at least 1 ms.

18. Apparatus according to claim 16, wherein the pulse train has a period of at least 5 ms.

19. Apparatus according to claim 18, wherein the pulse train has a period of at least 20 ms.

20. Apparatus according to claim 16, wherein the train of pulses has a duty cycle between about 10% and 50%.

21. Apparatus according to claim 16, wherein the train of pulses comprises square wave pulses.

22. Apparatus according to claim 16, wherein the train of pulses comprises sinusoidal pulses.

23. Apparatus for heart pacing with hemodynamic enhancement, comprising:

one or more electrodes, which convey electrical signals to respective cardiac muscle segments; and

signal generation circuitry, which applies an extended pacing signal to the one or more electrodes so as to pace the heart, the signal having an amplitude at least three times as great as a threshold for pacing the heart, but not sufficient for cardioversion.

24. Apparatus according to claim 23, wherein the signal has a duration at least three times a threshold duration for pacing the heart at the amplitude of the signal.

25. Apparatus according to any of the preceding claims, wherein application of the extended pacing signal modifies a characteristic of pulsatile flow of blood in the heart.

26. Apparatus according to claim 25, wherein the applicatof the extended pacing signal increases a stroke volume of the heart by at least 5% relative to the stroke volume when the heart is paced with pulses less than 2 ms in duration.

27. Apparatus according to claim 26, wherein the application of the extended pacing signal increases the stroke volume by at least 10% relative to the stroke volume when the heart is paced with pulses less than 2 ms in duration.

28. Apparatus according to claim 25, wherein the application of the extended pacing signal modifies a cardiac output of the heart by at least 5% relative to the cardiac output when the heart is paced with pulses less than 2 ms in duration at a pacing rate equal to that of the extended pacing signal.

29. Apparatus according to claim 25, wherein the application of the extended pacing signal increases a contractility of at least a portion of the heart by at least 10% relative to the contractility thereof when the heart is paced with pulses less than 2 ms in duration.

29. Apparatus according to claim 25, wherein the application of the extended pacing signal decreases a contractility of at least a portion of the heart by at least 10% relative to the contractility thereof when the heart is paced with pulses less than 2 ms in duration.

30. Apparatus according to claim 25, wherein the application of the extended pacing signal modifies a muscular tension in the heart by at least 10% relative to the tension when the heart is paced with pulses less than 2 ms in duration.

31. Apparatus according to any of claims 1-24, wherein application of the extended pacing signal modifies the duration of an action potential in the respective cardiac muscle segments by at least 10% relative to the duration when the heart is paced with pulses less than 2 ms in duration.

32. Apparatus according to any of claims 1-24, wherein the signal generation circuitry comprises a pulse generator and a DC offset generator, whose outputs are summed to provide the extended pacing signal.

33. Apparatus according to any of claims 1-24, wherein the one or more electrodes comprise a plurality of electrodes, which are positioned in different chambers of the heart.

34. Apparatus according to claim 33, wherein the signal comprises a plurality of waveforms, which are applied respectively to the electrodes in the different chambers according to a predetermined time sequence.

35. Apparatus according to claim 33, wherein a pacing pulse having a duration less than 8 ms is applied to one or more of the electrodes positioned in a first one of the different chambers, and wherein the extended pacing signal is applied to another one or more of the electrodes positioned in a second one of the different chambers.

36. Apparatus according to any of claims 1-24, wherein the signal generation circuitry applies the extended pacing signal to the one or more electrodes in response to a demand for an enhancement of hemodynamic performance of the heart.

37. Apparatus according to claim 36, wherein the enhancement of hemodynamic performance comprises an increase in cardiac output.

38. Apparatus according to claim 36, and comprising a sensor which generates an output responsive to a physiological parameter indicative of the demand for the enhancement, wherein the signal generation circuitry applies the extended pacing signal responsive to the output from the sensor.

39. Apparatus according to claim 36, wherein in the absence of the demand for the enhancement, the signal generation circuitry applies pacing pulses to the electrodes of substantially lower energy than the extended pacing signal.

40. Apparatus according to any of claims 1-24, wherein the one or more electrodes comprise endocardial electrodes.

41. Apparatus according to any of claims 1-24, wherein the one or more electrodes comprise epicardial electrodes.

42. Apparatus according to any of claims 1-24, wherein the one or more electrodes comprise transmyocardial electrodes.

43. Apparatus according to any of claims 1-24, wherein the one or more electrodes comprise transvenous electrodes.

44. Apparatus according to any of claims 1-24, and comprising a sensor, coupled to generate a signal responsive to activity of the heart, wherein the signal generation circuitry receives the signal from the sensor and modifies the extended pacing signal responsive thereto.

45. Apparatus according to claim 44, wherein the sensor comprises an electrode.

46. Apparatus according to claim 45, wherein the electrode senses a Monophasic Action Potential signal.

47. Apparatus according to claim 45, wherein the sensor comprises a pair of closely-spaced bipolar electrodes, which sense a local endocardial action potential.

48. Apparatus according to claim 44, wherein the signal generation circuitry detects a possible arrhythmic stimulation of the heart and modifies the extended pacing signal so as to prevent the arrhythmic stimulation.

49. A method for heart pacing with enhancement of cardiac contraction, comprising:

applying one or more electrodes to a subject's heart; and

conveying an extended pacing signal, having an overall duration of at three times a chronaxie time, to the one or more electrodes so as to pace the heart.

50. A method according to claim 49, wherein the overall duration is at least 10 ms.

51. A method according to claim 50, wherein the overall duration is at least 20 ms.

52. A method according to claim 49, wherein the overall duration is less than approximately 100 ms.

53. A method according to claim 49, wherein the cardiac muscle segments to which the one or more electrodes are applied are characterized by a refractory period, and wherein the overall duration of the signal is such that the signal terminates during the refractory period.

54. A method according to claim 49, wherein the signal has a leading edge and a trailing edge, and wherein the trailing edge is characterized by an absolute rate of voltage change substantially smaller than that of the leading edge.

55. A method according to claim 54, wherein the absolute rate of the voltage change is less than a minimum rate of change necessary to generate an action potential in the cardiac muscle segments.

56. A method according to claim 49, wherein the signal has an amplitude at least three times as great as a threshold for pacing the heart, but not sufficient for cardioversion.

57. A method according to claim 56, wherein the signal has a duration at least three times a threshold duration for pacing the heart at the amplitude of the signal.

58. A method according to claim 49, wherein conveying the extended pacing signal comprises conveying a train of pulses.

59. A method according to claim 58, wherein each of the pulses in the train has a pulse duration of at least 1 ms.

60. A method according to claim 58, wherein the train of pulses has a period of at least 5 ms.

61. Apparatus according to claim 60, wherein the train of pulses has a period of at least 20 ms.

62. A method according to claim 58, wherein conveying the train of pulses comprises conveying a plurality of biphasic pulses.

63. A method according to claim 58, wherein the train of pulses has a duty cycle between about 10% and 50%.

64. A method for heart pacing with hemodynamic enhancement, comprising:

applying one or more electrodes to the heart; and

conveying an extended pacing signal, comprising a train of a plurality of biphasic pulses, to the one or more electrodes so as to pace the heart.

65. A method according to claim 64, wherein each of the pulses in the train has a pulse duration of at least 1 ms.

66. A method according to claim 64, wherein the train of pulses has a period of at least 5 ms.

67. Apparatus according to claim 66, wherein the train of pulses has a period of at least 20 ms.

68. A method according to claim 64, wherein the train of pulses has a duty cycle between about 10% and 50%.

69. A method according to claim 64, wherein conveying the train of pulses comprises conveying square wave pulses.

70. A method according to claim 64, wherein conveying the train of pulses comprises conveying sinusoidal pulses.

71. A method for heart pacing with hemodynamic enhancement, comprising:

applying one or more electrodes to the heart; and

conveying an extended pacing signal to the one or more electrodes so as to pace the heart, the signal having an amplitude at least three times as great as a threshold for pacing the heart, but not sufficient for cardioversion.

72. A method according to claim 71, wherein the signal has a duration at least three times a threshold duration for pacing the heart at the amplitude of the signal.

73. A method according to any of claims 49-72, wherein conveying the extended pacing signal comprises modifying a characteristic of pulsatile flow of blood in the heart.

74. A method according to claim 73, modifying the characteristic comprises increasing a stroke volume of the heart by at least 5% relative to the stroke volume when the heart is paced with pulses less than 2 ms in duration.

75. A method according to claim 74, wherein increasing the stroke volume comprises increasing the stroke volume by at least 10% relative to the stroke volume when the heart is paced with pulses less than 2 ms in duration.

76. A method according to claim 73, wherein modifying the characteristic comprises modifying a cardiac output of the heart by at least 5% relative to the cardiac output when the heart is paced with pulses less than 2 ms in duration at a pacing rate equal to that of the extended pacing signal.

77. A method according to claim 73, wherein modifying the characteristic comprises increasing a contractility of at least a portion of the heart by at least 10% relative to the contractility thereof when the heart is paced with pulses less than 2 ms in duration.

78. A method according to claim 73, wherein modifying the characteristic comprises decreasing a contractility of at least a portion of the heart by at least 10% relative to the contractility thereof when the heart is paced with pulses less than 2 ms in duration.

79. A method according to claim 73, wherein modifying the characteristic comprises modifying a muscular tension in the heart by at least 10% relative to the tension when the heart is paced with pulses less than 2 ms in duration.

80. A method according to any of claims 49-72, wherein conveying the extended pacing signal comprises modifying the duration of an action potential in the respective cardiac muscle segments by at least 10% relative to the duration when the heart is paced with pulses less than 2 ms in duration.

81. A method according to any of claims 49-72, wherein conveying the extended pacing signal increases a muscular tension in the respective cardiac muscle segments by at least 50% relative to the duration when the heart is paced with pulses less than 2 ms in duration.

82. A method according to claim 81, wherein conveying the extended pacing signal increases the muscular tension in the respective cardiac muscle segments by at least 100% relative to the duration when the heart is paced with pulses less than 2 ms in duration.

83. A method according to any of claims 49-72, wherein applying the one or more electrodes comprises applying a plurality of electrodes in different chambers of the heart.

84. A method according to claim 83, wherein conveying the extended pacing signal comprises conveying a plurality of waveforms respectively to the electrodes in the different chambers according to a predetermined time sequence.

85. A method according to claim 83, and comprising conveying a pacing pulse having a duration less than 8 ms to one or more of the electrodes positioned in a first one of the different chambers, and wherein conveying the extended pacing signal comprises conveying the signal to another one or more of the electrodes positioned in a second one of the different chambers.

86. A method according to any of claims 49-72, wherein conveying the extended pacing signal comprises conveying the signal to the one or more electrodes in response to a demand for an enhancement of hemodynamic performance of the heart.

87. A method according to claim 86, wherein the enhancement of hemodynamic performance comprises an increase in cardiac output.

88. A method according to claim 86, and comprising receiving an output signal responsive to a physiological parameter indicative of the demand for the enhancement, and wherein

conveying the extended pacing signal comprises conveying the pacing signal responsive to the output signal.

89. A method according to claim 86, and comprising, in the absence of the demand for the enhancement, conveying pacing pulses to the electrodes of substantially lower energy than the extended pacing signal.

90. A method according to any of claims 49-72, wherein applying the one or more electrodes comprises applying electrodes endocardially.

91. A method according to any of claims 49-72, wherein applying the one or more electrodes comprises applying electrodes epicardially.

92. A method according to any of claims 49-72, wherein applying the one or more electrodes comprises applying electrodes transmyocardially.

93. A method according to any of claims 49-72, wherein applying the one or more electrodes comprises applying electrodes transvenously.

94. A method according to any of claims 49-72, and comprising receiving an output signal responsive to activity of the heart, and wherein conveying the extended pacing signal comprises modifying the pacing signal responsive to the output signal.

95. A method according to claim 94, wherein receiving the output signal comprises receiving an electrophysiological signal.

96. A method according to claim 95, wherein the electrophysiological signal comprises a Monophasic Action Potential signal.

97. A method according to claim 95, wherein receiving the electrophysiological signal comprises placing a pair of in close mutual proximity in contact with the heart and receiving a bipolar signal from the electrodes.

98. A method according to claim 94, wherein modifying the pacing signal comprises detecting a possible arrhythmic stimulation of the heart and modifying the extended pacing signal so as to the arrhythmic stimulation.

99. A method according to any of claims 49-72, wherein applying the one or more electrodes comprises applying electrodes such that conveying the extended pacing signal engenders a redistribution of cardiac muscle mass.

Sub B1

add A1